

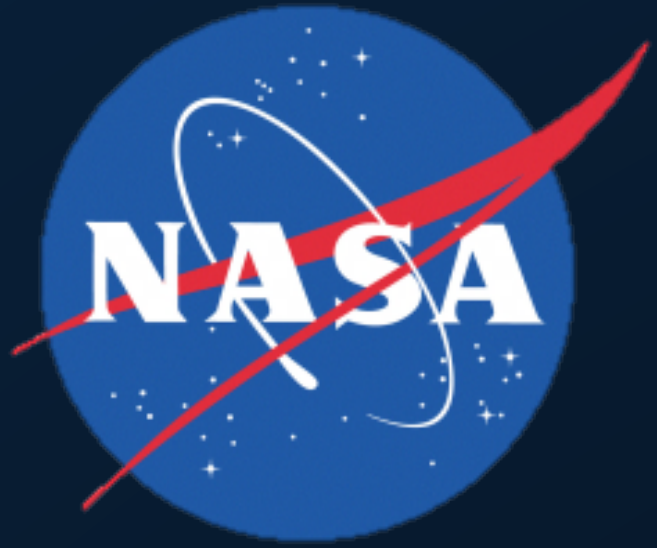
Characterizing the 2016 Perseid Meteor Shower Outburst

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Introduction & Predictions

The Perseid meteor shower has been observed for millennia and is known for its visually spectacular meteors and occasional outbursts. Normal activity displays Zenithal Hourly Rates (ZHRs) of ~ 100 . The Perseids were expected to outburst in 2016, primarily due to particles released during the 1862 and 1479 revolutions of parent Comet Swift-Tuttle. NASA's Meteoroid Environment Office predicted the timing, strength and duration of the outburst for spacecraft risk using the MSFC Meteoroid Stream Model [1]. A double peak was predicted, with an outburst displaying a ZHR of 210 ± 50 at 00:30 UTC Aug 12 (139.5° Solar Longitude), and a traditional peak ~ 12 hours later with rates still heightened from the outburst [2]. Video, visual, and radar observations taken worldwide by various entities were used to characterize the shower and compare to predictions.

Past Notable Perseid Outbursts:

- 1993: ZHR ~ 300 (delayed STS-51 Launch).
- 1994: ZHR of 230-350
- 1995: ZHR of 160-180
- 2004: ZHR of 187
- 2009: Triple outburst of ZHR ~ 180 -220 prior, during, and past traditional peak. See predictions and results below in Figure 3.

Why does this happen?

- Jupiter perturbs the trail of debris left by Comet 109P/Swift-Tuttle.



Figure 2: Perseids are known to be rich in bright meteors, such as this one seen August 13, 2011 by astronaut Ron Garan from the ISS.

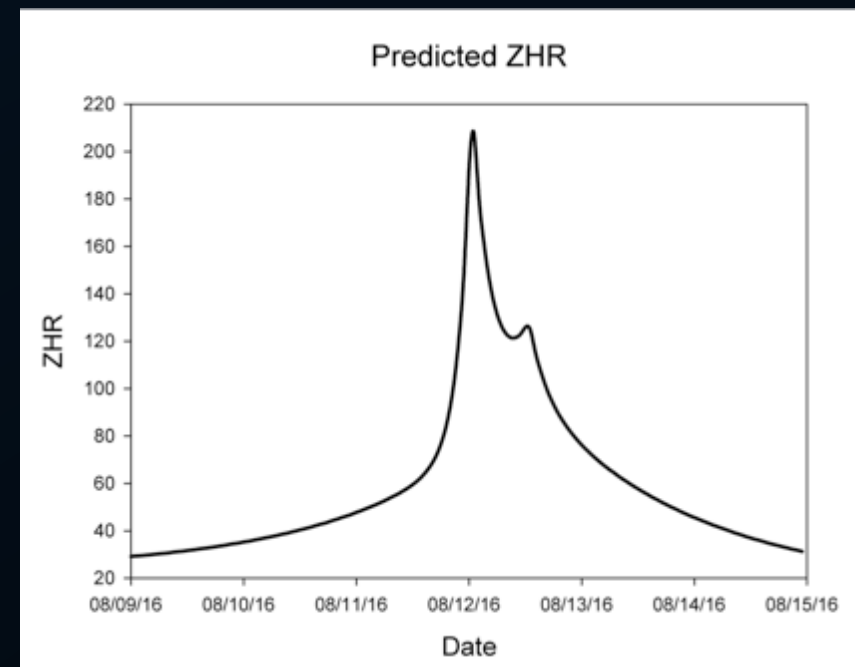


Figure 1: MSFC Meteoroid Stream Model results for 2016 Perseids. The first peak is the outburst with a ZHR of 210 at $\sim 139.5^\circ$ Solar Longitude, and the second peak is the traditional peak at $\sim 140.0^\circ$, with a ZHR of 125, still slightly heightened because of the outburst.

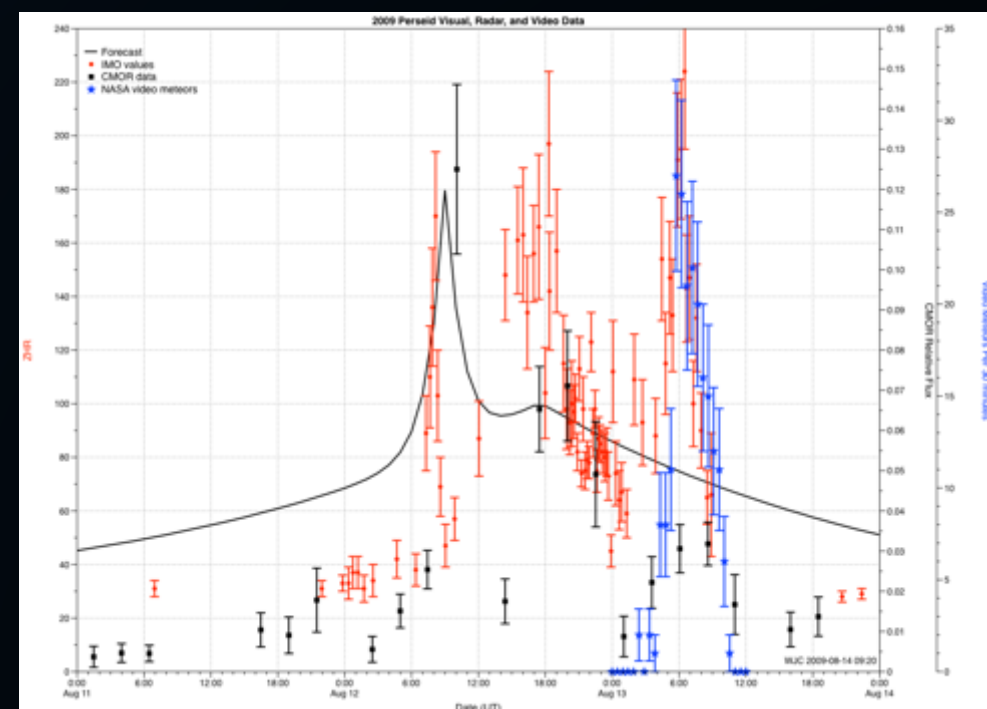


Figure 3: Prediction and results of the 2009 Perseid Outburst. Two outbursts occurred after the predicted outburst, as it seen in International Meteor Organization visual observations (red) and NASA All Sky video observations (blue). This indicates the importance in validating results.

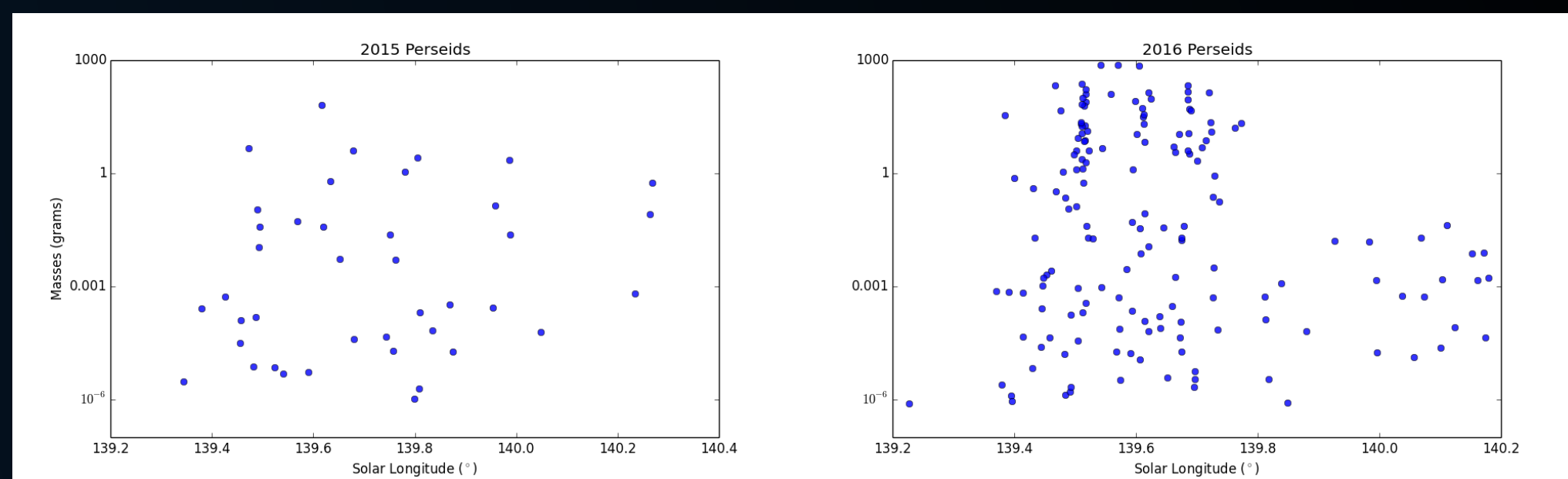


Figure 4: Particle mass prediction 2016 (left) and 2015 (right) for comparison to a non-outburst year. Note the most significant new component of particles not seen in a non-outburst year (2015) was in the more massive range, between 1-1000 gram particles, that was predicted from 139.4-139.6° SL.

All Sky Camera Network Results

- NASA's All Sky Fireball Network consists of 15 cameras, placed in 4 groups around continental USA to detect meteors brighter than the planet Venus (-4 magnitude).
- Meteors of this brightness correspond to cm-sized meteoroids, weighing ~ 1 gram.
- During 2016, clouds were over most of the networks approaching the peak of the Perseids, but cleared off soon after dark on the peak night.
- Being in North America and constrained by daylight, these cameras missed the outburst peak, but detected the period between the outburst peak and the normal peak.
- Rates were heightened in 2016 over 2015.



Figure 5: 2016 Perseids as seen in NASA MEO's All Sky camera located in Tullahoma, TN. The Perseid radiant is in the upper left quadrant. The Moon is seen setting in the lower right.

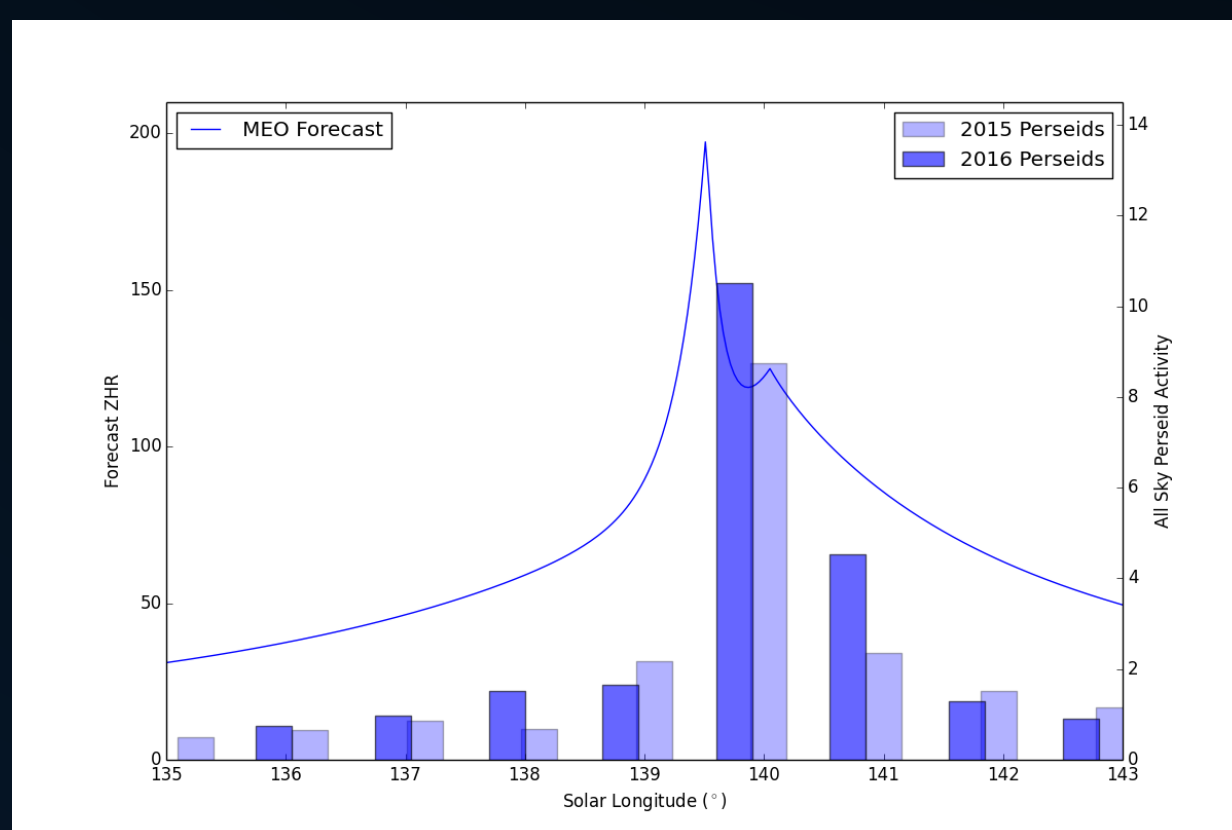


Figure 6: 2016 Perseid rate as seen in NASA's All Sky Fireball Network. Shown here is a corrected activity. Raw numbers were scaled by the Perseid radiant altitude and clear observing times in every camera, and how much each additional clear camera added in area. 2015 is shown for comparison. 176 Perseids were seen in 2016 compared to 277 in 2015, however when taking into account the cameras that were clear vs. cloudy and going from raw numbers to a meaningful activity, 2016 showed heightened rates between the outburst and normal Perseid peaks. Bar size and position indicates observing time/duration.

IMO Video and Visual Observations

Most of North America was in daylight during the outburst peak, thus the International Meteor Organization (IMO) video observations and visual observations were heavily relied upon to characterize the outburst peak.

- The IMO video network had more than 70 cameras in operation in August 2016 with 12,000 effective observing hours and 96,000 detected meteors.
- Detects meteoroids between 0.0001-0.1 grams. These observations are used to calculate fluxes to $+6.5$ magnitude and ZHRs using a population index of 2.2.
- 339 visual observers contributed in the 2016 Perseid campaign (see Figure 10).
- The IMO visual observations resulted in ZHRs, converted to fluxes $+6.5$ magnitude using a population index of 2.0[3].
- Results were provided by Sirko Molau. See [8] for full IMO video and visual results.

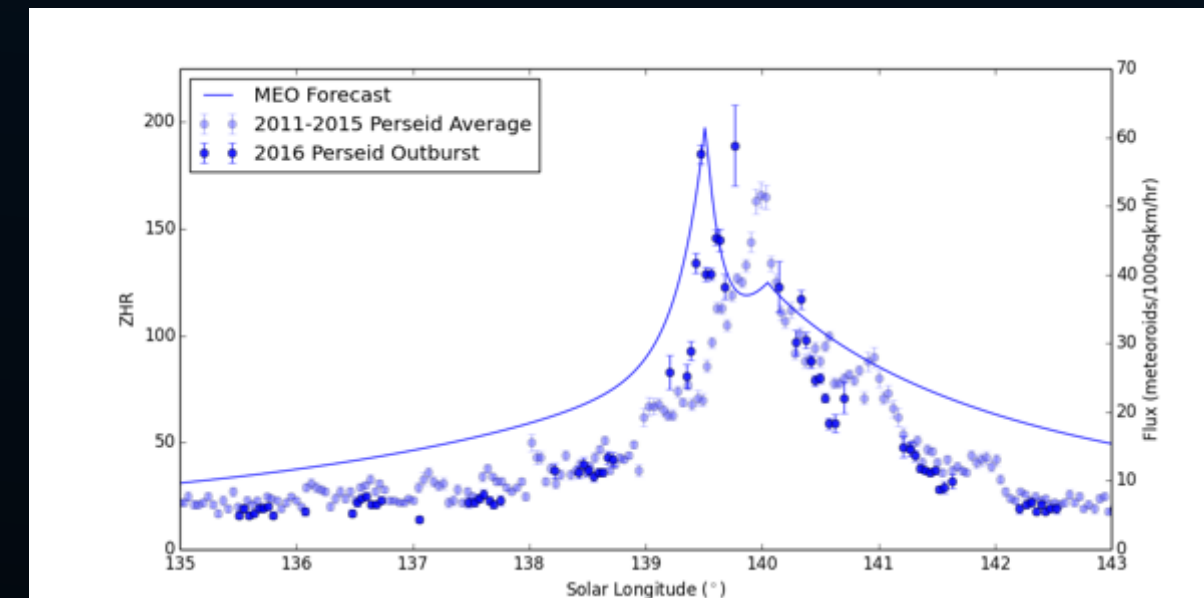


Figure 7: IMO video results of Perseid activity. 2016 activity (dark) is contrasted with the average activity of 2011-2015 (light), which were all non-outburst years. 2016 Perseid activity is seen to be higher prior to the traditional peak.

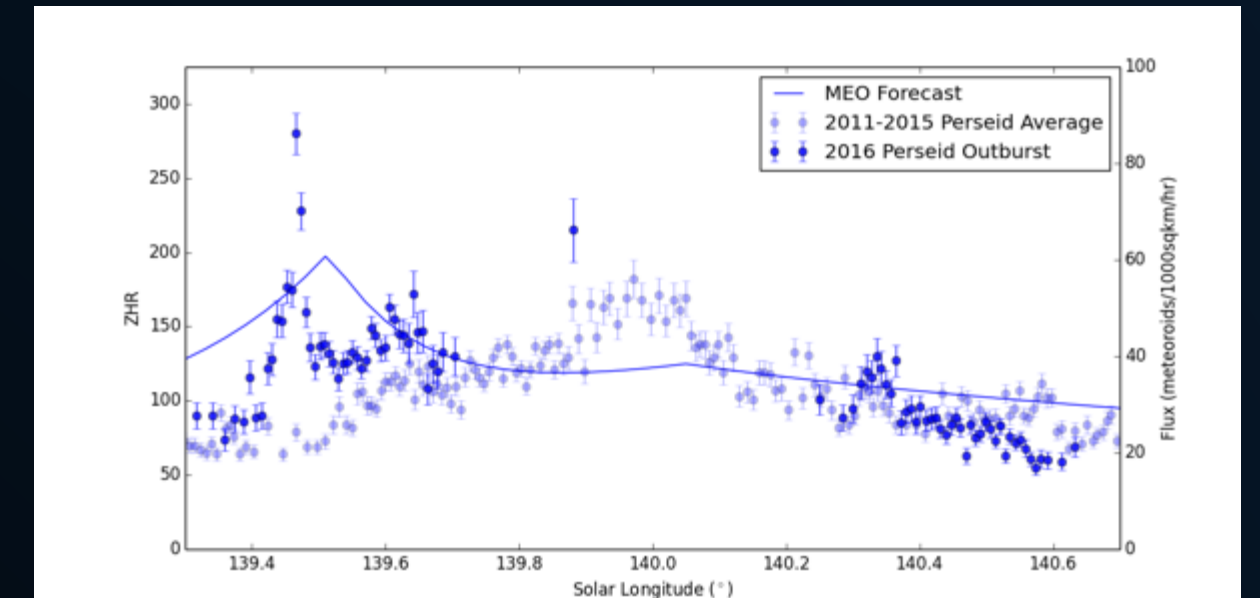


Figure 8: IMO video results of peak Perseid activity. 2016 Activity (dark) contrasted with 2011-2015 activity (light), which were all non-outburst years. Between 139° and 140° SL, when Earth passed the 1862 and 1479 dust trails, the rates were clearly higher than average. Solar longitudes 139.7° to 140.3° were daylight in Europe in 2016, where most video cameras are located.

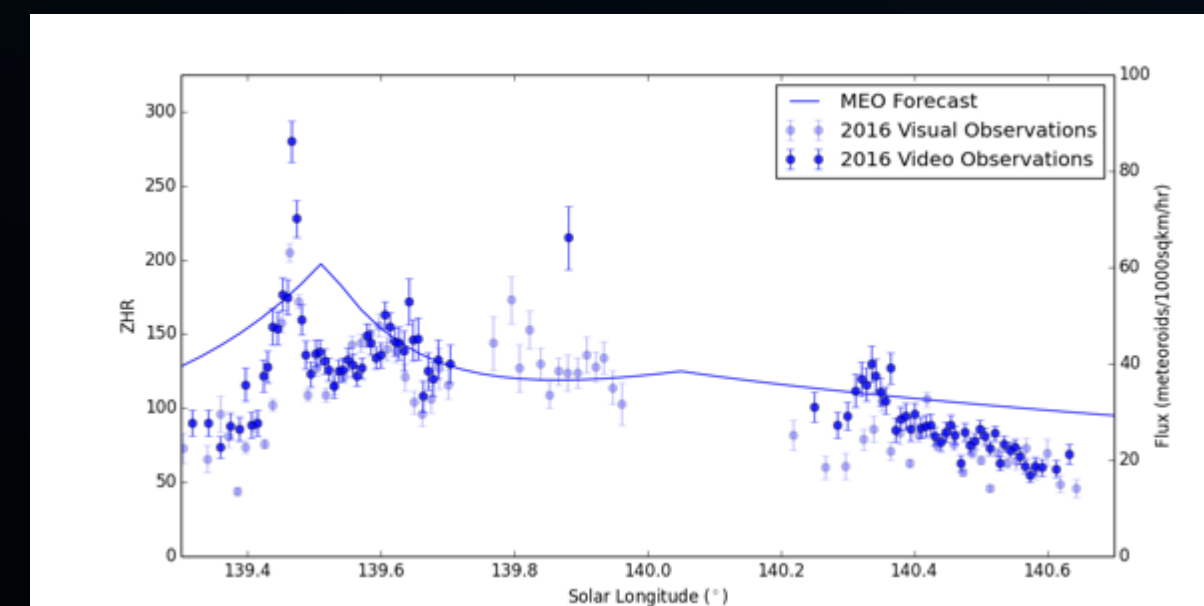


Figure 9: IMO video results (dark) compared to IMO visual observations (light) for the 2016 Perseids. Note that visual observations were processed with a population index of $r=2.0$, and video data with $r=2.2$. Lack of data indicates daylight in Europe. Visual reports confirm video results, showing an outburst peak at 139.5° SL. High-resolution displays show that rates were most enhanced between 22:15 and 23:45 UTC August 12 [8].



Figure 10: Distribution of visual reporters around the world. (IMO)

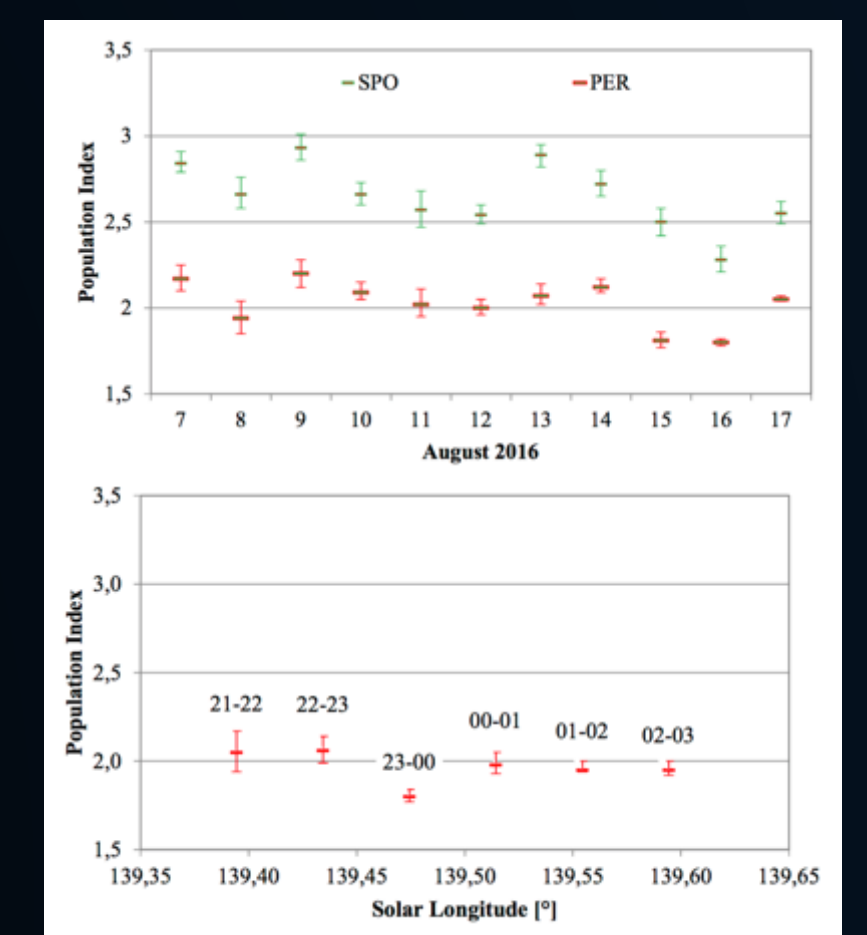


Figure 11 (top) shows the population index profile of the Perseids and sporadic meteors between August 7 and 17 (135° - 145° SL). The Perseid population index indicates the distribution of particle sizes in the meteoroid stream. The Perseids' population index hovers around 2.0, with an average index that is 0.6 less than the sporadic index. Figure 11 (bottom) is zoomed in on the outburst peak. The smallest pop index is from 23:00-00:00 which has a population index of 1.8. Plots by Sirko Molau [8].

MAARSY Results

- Middle Atmosphere Alomar Radar System (MAARSY) is an HPLA radar employing an active phased array antenna suitable to monitor the Perseid radiant [6,7].
- It was modified to conduct continuous meteor observations and meteor shower studies in 2016 for the Perseid outburst.
- System has a limiting mass of 10^{-6} - 10^{-7} grams.
- In 2015 and 2016, MAARSY detected enough Perseid meteors to produce an activity curve with 3 hour bins.
- Activity is comparable from 2015 to 2016; no notable outburst in this small size range.
- The population index is low – 1.8 during the peak of the outburst indicating the outburst may have been rich in bright particles, not the low-mass particles that MAARSY detects (Figure 11). Additionally, Figure 4 indicates that the most significant new component of particles for the 2016 outburst is in a more massive range.

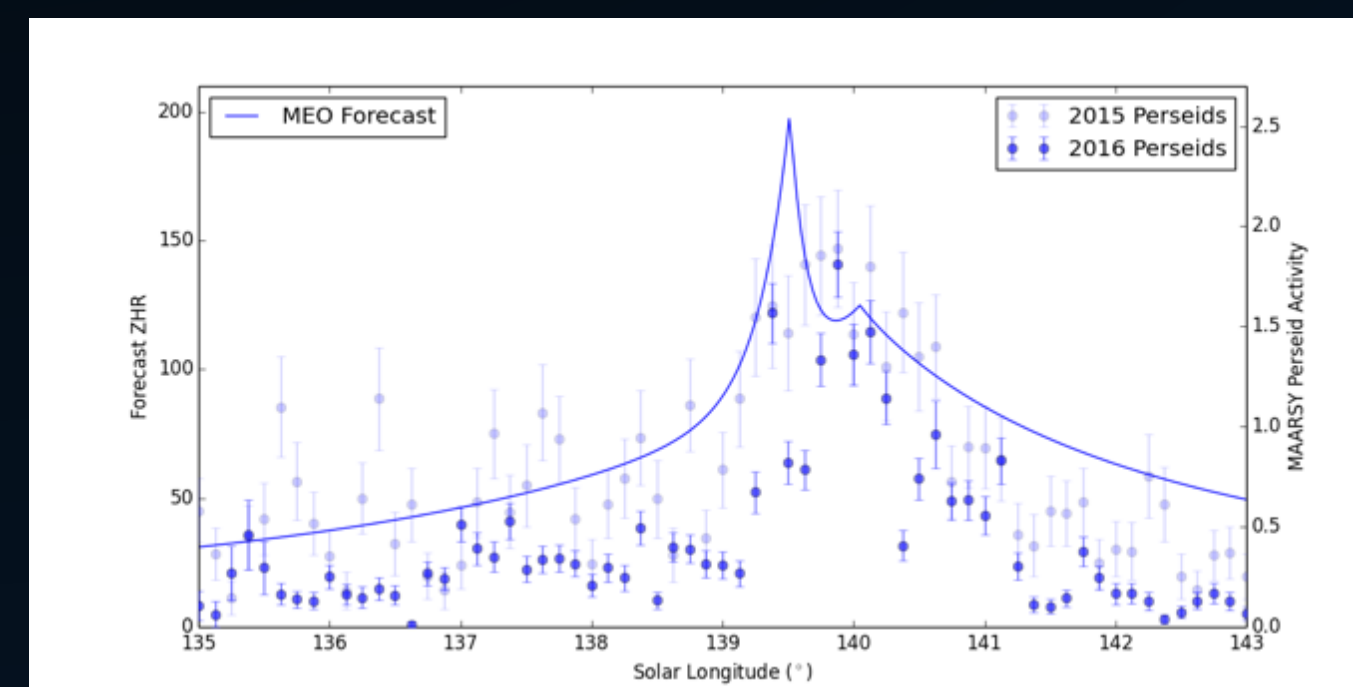


Figure 12: Perseid activity as seen in MAARSY in 2016 and 2015. Corrected activity takes raw activity and scales by radiant altitude as well observation time. Error bars are due to number statistics. As error bar size indicates, more Perseids were detected in 2016, though this is offset by the increased observation time.

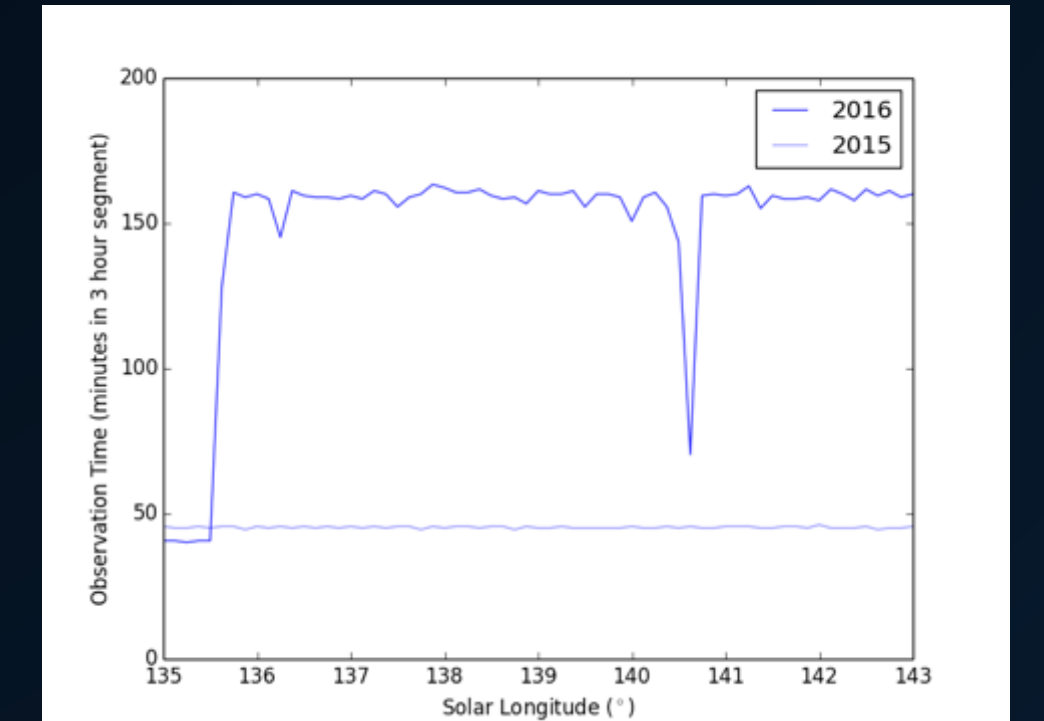


Figure 13: MAARSY observation time in 2016 and 2015. Plot represents how many minutes of observation time occurred in each 3 hour bin.

Conclusions

- NASA's Meteoroid Environment Office predicted a Perseid Outburst in 2016 with a peak ZHR of 210, 12 hours prior to the traditional peak, and a traditional peak still heightened from the outburst.
- The outburst was clearly seen in IMO Video & Visual results, as well as NASA's All Sky Fireball Network data. The peak of the outburst was seen to have a ZHR of 280 according to IMO video observations, and 205 as seen in visual observations.
- The outburst was not seen in MAARSY, which has a limiting mass of 10^{-6} - 10^{-7} grams.
- This indicates the outburst was detected primarily in larger particles over smaller particles.
- NASA's MEO correctly predicted the timing and approximate strength.
- The forecast over-predicts the flux from Perseids approaching and leaving the peak, particularly in large sizes as seen in Figures 6 and 7.

References

[1] Moser, D.E. and Cooke, W.J. (2008) *EM&P*, 109, 285-291. [2] Moser, D.E. and Cooke, W.J. (2015) *Stanford Meteor Environment and Effects Workshop*. M16-5103 [3] Koschack, R. and Rendtel, J. (1990) *WGN*, 18, 119-140. [4] Molau, S. and Barentsen, G. (2014) *Meteoroids 2013 Proceedings*, 297-305. [5] Blaauw, R.C., Campbell-Brown, M. and Kingery, A. (2016) *MNRAS*, 463(1), 441-448. [6] Stober G., Schult C., et al. (2013) *Ann. Geophys.*, 31, 473-487. [7] Schult C., Stober G., et al. (2016) *ICARUS*, submitted. [8] Molau, S. (2016) *Results of the IMO Video Meteor Network – August 2016*. <http://www.imonet.org/reports/201608.pdf>.